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MTL TR 88-49

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REDUCTION OF M1 WELD FABRICATION COSTS - THE EFFECT OF WELD SHIELDING GAS COMPOSITION

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MATERIALS PRODUCIBILITY BRANCH

December 1988

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US ARMY
LABORATORY COMMAND
MATERIALS TECHNOLOGY LABORATORY

U.S. ARMY MATERIALS TECHNOLOGY LABORATORY
Watertown, Massachusetts 02172-0001

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: MTL TR 88-49	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): REDUCTION OF M1 WELD FABRICATION COSTS - THE EFFECT OF WELD SHIELDING GAS COMPOSITION	5. TYPE OF REPORT & PERIOD COVERED: Final Report
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): Steven A. Gedeon and James E. Catalano	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: U.S. Army Materials Technology Laboratory, Watertown, Massachusetts 02172-0001, SLCMT-MEM	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: D/A Project No. 1L162105.AH84, AMCMS Code No. 612105.H84
11. CONTROLLING OFFICE NAME AND ADDRESS: U.S. Army Laboratory Command, 2800 Powder Mill Road, Adelphi, Maryland 20783-1145	12. REPORT DATE: December 1988
	13. NUMBER OF PAGES: 30
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Armor steel, Welding, Fabrication, Mechanical tests, Cost reduction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(SEE REVERSE SIDE)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Block No. 20

ABSTRACT

This project was initiated in October, 1986, to find a lower cost alternative to the weld shielding gas used for M1 fabrication at the U.S. Army Lima Tank Plant. The shielding gas in use was a newly patented mixture termed "Transferred Ionized Molten Energy" (TIME) gas. This gas was manufactured in Canada (and for a short time in Chicago, and now Columbus), and is much more expensive than other gas mixtures.

The objective of this project is to evaluate a wide variety of weld shielding gas mixtures for welding the armor steel used in the U.S. Army M1 Abram's main battle tank. It is greatly desired to find an inexpensive gas mixture to replace the TIME gas used in 1986 at the Lima Army Tank Plant without decreasing weld performance.

The gas mixtures were evaluated on gas cost, deposition rate, amount of weld hydrogen, bead profile, and amount of spatter. The effects of gas composition, weld voltage, electrode stickout, base metal composition, and nozzle geometry on welding characteristics were also evaluated.

The results of this project show that a number of lower cost gases exist which are as good or better than the TIME gas. General Dynamics (GD) has performed mechanical and ballistic tests using Ar/5% O_2, TIME (Ar/He/CO_2/O_2), and STARGON (Ar/CO_2/O_2), and has taken steps to use 95% Ar/5% O_2 throughout their entire facility. This will amount to an estimated cost savings of approximately $1 million per year, which is documentated in this report.

Even further cost reductions are now being proposed within an MTL/GD joint value engineering proposal to TACOM.

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INTRODUCTION

The primary welding process used for joining thick section steel components in the U.S. Army M1 main battle tank is gas metal arc welding (GMAW). This process requires the use of a shielding gas to protect the molten steel from atmospheric contamination and to provide the desired welding arc characteristics. A variety of gases and gas mixtures are used depending on the metal and type of joint being welded.

A sufficient flow of any of the inert gases will prevent atmospheric contamination. Atmospheric elements such as nitrogen can reduce the ductility and impact strength of steel welds. Contamination with hydrogen can cause hydrogen embrittlement which may result in catastrophic failure of weldments.

Active gases such as CO_2 or O_2 are often added to the inert shielding gas when GMA welding steel. They promote arc stability, puddle fluidity, and good fusion between the weld and base material.

Shielding gases also determine the mode of metal transfer[1] from the filler metal to the weld pool, and the depth to which the work piece is melted (depth of penetration). The physical properties of gases that affect their performance characteristics include: density, ionization potential, oxidizing potential, electrical conductivity, and thermal conductivity. Rather than examine the effect of each property individually, the effect of each gas on performance characteristics will be briefly reviewed.

Pure argon is usually used for all-position welding aluminum, zirconium, titanium, and nickel base alloys. It provides excellent spray transfer characteristics but is seldom used on steel without being mixed with one of the active gases. Argon is the cheapest inert gas available in the United States.

Helium does not provide as stable of an arc as does argon. However, due to its higher thermal conductivity, it is reported to develop a broader weld pool. Argon-helium mixtures are often used to obtain the low spatter and arc stability of argon as well as the increased heat input of helium. The mixture 25% Ar-75% He is commonly used for automated welding of thick section nonferrous materials, but is infrequently used for steel.

The active gases CO_2 and O_2 basically provide the same performance characteristics, and one or the other is almost always added to the inert gases when welding steel. Oxygen is the more oxidizing of the two, so about one-half to one-tenth as much is usually used than if CO_2 was added. Oxygen additions are usually between 1 and 5%, whereas CO_2 can be up to 50%. Pure CO_2 can be used for a number of applications such as low current short circuiting transfer, but the arc tends to be too violent with a great amount of spatter. Desirable spray transfer is not obtained when the gas mixture contains more than about 15% CO_2.[1] Instead, the resulting transfer mode is globular which tends to produce excess spatter.

A number of triple gas mixes of Ar/He/CO_2 have been developed for use in short circuit transfer welding, also known as short arc welding. These have found limited applications to date, primarily out of position welding of stainless steel. One commercial mixture, Linde's STARGON, combines Ar/O_2/CO_2 and can be used for spray transfer.

A four-gas mixture has recently been developed which combines Ar/He/CO_2/O_2. This mixture is being distributed under the trade name of "Transferred Ionized Molten Energy" (TIME) and has a composition of 25-35% He, 6.7-8.5% CO_2, 0.3-0.8% O_2, and the balance argon for carbon steel; and 52-60% He, 2.5-3.4% CO_2, 0.1-0.3% O_2, and the balance argon for stainless steel. Due to the fact that this mixture has been patented and is manufactured exclusively in Canada, it is much more expensive than any of the other mixtures.

The TIME gas has received some publicity[2] and shows promise for increasing weld deposition rates. Magusin[3] has found that welds made with TIME gas can exhibit sufficient mechanical properties, but did not compare the TIME gas

1. *MIG Welding Handbook.* Union Carbide Corporation, Linde Division, Donbury, CT January 1984.
2. BIRCHFIELD, J.R. *High-Rate Welds Need More Current, a Different Gas, and Gun Cooling.* Weld Design and Fabrication, June 1985.
3. MAGUSIN, J. *Mechanical Properties of EHS and AR Steel Welded with TIME Process.* Svensktal TR 87-0303, February 1987.

welds to welds made with other gases. Rodwell[4] compared TIME gas to Ar/20% CO_2 and found that the TIME gas could exhibit higher deposition rates. However, he never used the same electrode extension on both gases; the TIME gas welds always had a 29-mm extension and the Ar/20% CO_2 always had an 18-mm extension. Also, the TIME gas was always welded with a higher voltage. Since it is very well known that increasing electrode extension and voltage increase deposition rates, his study must be considered inconclusive. Additionally, it is known that mixtures with more than 15% CO_2 are normally used for low current short circuit transfer, not for high deposition rate welding.

Since no direct comparisons of the weldability of different gases using identical welding conditions (including identical nozzle, stickout, voltage, current, etc.) are available, this investigation will concentrate on direct comparison experiments. Perhaps the lack of direct comparisons is due to the misnomer of referring to the use of TIME gas as a "TIME process." The correct term is the gas metal arc welding process using a TIME gas and nozzle. The TIME nozzle is recessed which forces the use of a larger electrode extension which, in turn, gives higher deposition rates. Neither the American Welding Society, National Bureau of Standards, Department of Defense, or International Institute of Welding recognize the existence of a TIME process. TIME is simply the trade name developed by the gas's distributor, Weld Process International.

EXPERIMENTAL PROCEDURE

A Linde 650 CV/CC power supply was used in the constant voltage mode for GMAW. This has a maximum output of 44 volts and 650 amps at 100% duty cycle. A Linde Digimatic II controller was used and the maximum wire feed rate was 2000 inches per minute (ipm).

Most welding was performed on high hard armor steel conforming to MIL-A-46100. This steel composition, along with the composition of the Linde 95 welding filler metal conforming to AWS A5.28-79 (ER-100S-1), is shown in Table 1.

Table 1. COMPOSITION OF THE STEEL USED IN THIS STUDY

	C	Si	Mn	Cu	P	Ni	S	Al	Cr	Mo
MIL-A-46100	0.31	0.41	0.97	0.38	0.011	1.21	0.008	0.044	0.51	0.50
Linde 95	0.06	0.35	1.65	--	0.007	1.75	0.020	--	0.10	0.35

Two types of gas nozzles were used: A TIME torch purchased from Weld Process International, and a conventional nozzle purchased from Linde. Thirteen gas mixtures were evaluated: Pure argon, 75% Ar/25% He, 65% Ar/35% He, 50% Ar/50% He, 25% Ar/75% He, Ar/2% O_2, Ar/5% O_2, Ar/5% CO_2, 65% Ar/25% He/10% CO_2, 70% Ar/25% He/5% CO2, TIME 1, TIME 2, and TIME 3.

Bead-on-plate GMA welds were performed at four voltages, two electrode stickout distances, and with two different nozzles. At each of these 16 conditions, the wire feed rate was increased to determine the transition current from globular to spray, and from spray to rotational metal transfer. The maximum deposition rate was then calculated for welds with stable metal transfer. Bead profile and depth of penetration were also determined for stable welds with maximum current.

Diffusible weld hydrogen was measured for representative welds on both high hard armor steel conforming to MIL-A-46100 and mild steel (A36). Based on results of a related research effort at MTL,* the American Welding Society method A4.3-86 was used with a Yanaco hydrogen analyzer model G-1006. This method is based on gas chromatography to ensure that only hydrogen is measured and that solubility errors associated with the glycerin test method are eliminated.

* GEDEON, S. A. *Measurement of Hydrogen in Welds.* Results to be published.

4. RODWELL, M. H. *Evaluation of the Performance Process MIG Welding System.* The Welding Institute, LD 22983/83, 1983.

After all of the previous results were analyzed and a cost comparison performed, mechanical property specimens were welded using three gas mixtures and three heat inputs. The mechanical properties measured included: yield strength, ultimate tensile strength, percent elongation, percent reduction in area, and Charpy V-notch.

RESULTS

Screening tests confirmed that gas mixtures which did not contain active gases such as O_2 or CO_2 were unsatisfactory for welding steel due to poor arc stability, excess spatter, and poor puddle fluidity. However, various Ar/He mixtures were used later in this study to understand the effect of helium on deposition rate and current.

Bead-on-plate GMA welds were made at 25, 30, 35, 40, and 44 volts, and the wire feed rate increased to determine the maximum deposition rate possible before the arc became unstable.

Figures 1 through 7 show the range of globular, spray, and rotational metal transfer as a function of arc voltage for the seven remaining gases. These figures are presented as the maximum wire feed rate that will sustain globular or spray transfer at each voltage. Figures that do not show data points for the lower voltages indicate that satisfactory welds could not be made at those welding conditions. At 1-3/16" tip to work distance (referred to here as stickout), 95% Ar/5% O2 was the only gas to exhibit satisfactory welds at all voltages. However, it also had the lowest transition from spray to rotational metal transfer.

All of the gases studied (not including the Ar/He mixtures) could sustain quasi-stable rotational metal transfer at feed rates of up to 2000 ipm. However, once the spray to rotational transition is passed, the definition of maximum acceptable wire feed rate becomes unclear. The issue of maximum acceptable deposition rate will be addressed in the Discussion section.

Figures 8 through 14 illustrate the effect of using the TIME torch nozzle while maintaining a constant electrode extension. The TIME nozzle had little effect on most of the transition ranges except that it significantly increased the spray range for the 95% Ar/5% O_2 gas, while sacrificing the ability to weld at low voltages. The TIME nozzle also stabilized the spray transfer at very high voltages for the TIME 2 gas.

The stickout was varied to show the effect on the globular, spray, and rotational transfer regions. Figures 15 through 17 illustrate the resulting ranges for three gases at 3/4" stickout. The lower stickout increased the ranges of the 95% Ar/5% O_2 and 95% Ar/5% CO_2 gases, but reduced the range of the TIME 2 gas.

The use of the TIME torch nozzle at 3/4" stickout is compared in Figures 18 through 20. The TIME torch nozzle seems to have either little effect or an adverse effect at the lower stickouts.

Regardless of the nozzle, the lower stickout reduced the maximum rotational wire feed rate. This was due to the arc becoming "buried" at the higher feed rate. The arc would become unstable with a resulting violent pool action and excessive spatter.

The amount of hydrogen absorbed as a function of gas and base metal composition was determined. The amount of diffusible hydrogen was determined using the procedures set forth in AWS A4.3-86.

Figure 21 shows the diffusible hydrogen content of welds made with spray metal transfer (low deposition GMAW parameters in Table 2) as a function of the amount of oxygen is the argon shielding gas. Figure 22 shows the effect of various additions of CO_2. Figure 23 compares the effect of adding 2% O_2 and 2% CO_2 to the pure argon shielding gas.

The diffusible hydrogen content of TIME 2 gas welds is shown in Figure 24. Also shown in this figure, are welds made with the 65% Ar/25% He/10% CO_2 shielding gas. As can be seen, both the three- and four-part combinations containing helium absorb much more hydrogen than any of the binary gas mixtures.

The effect of base metal composition is demonstrated in Figure 25. In this experiment, high hard armor steel was used for the diffusible hydrogen specimen rather than the mild steel specimens normally used in AWS A4.3-86. As can be seen, the armor steel picks up much more hydrogen than mild steel. This trend is reiterated in Figure 26 which shows that armor steel picks up more hydrogen using 98% Ar/2% O_2 gas as well. Figure 27 confirms that 46100 welds made with 2% CO_2 absorb less hydrogen than welds made with 2% O_2.

Table 2. WELDING PARAMETERS USED IN THIS STUDY (UNLESS OTHERWISE STATED)

Process	Low Dep GMAW	High Dep GMAW
Voltage	30 Volts	40 Volts
Current (approx)	220 Amps	400 Amps
Travel Speed	20 in./min	28 in./min
Wire Feed Rate	350	1000
Contact Tip-to-Work	1-3/16"	1-3/16"
Preheat	75°F	75°F
Electrode Diameter	0.045"	0.045"
Polarity	DCRP	DCRP
Gas Flow Rate	60 cf/h	60 cf/h

The effect of metal transfer mode and shield gas composition on the resulting weld bead profiles were determined. Figure 28 shows cross sections of welds made with rotational metal transfer. As can be seen, shield gases containing helium, results in welds with deposition, finger-like penetration. The Ar/5% CO_2 weld has a nice hemispherical profile with good penetration, and the Ar/5% O_2 has a broad, shallow bead profile.

Conversely, when welding in the spray transfer mode (Figure 29), the effect of shield gas composition is reversed. The weld-containing helium exhibits the shallowest and broadest penetration, and both of the nonhelium-containing welds have finger-like penetration.

When welding in the globular transition mode (Figure 30), the bead profiles are much more similar to each other. However, the helium containing gas results in the most finger-like appearance.

Bead-on-plate welds were made with rotational metal transfer at wire feed rates of from 1000 to 2000 ipm in 100-unit increments using Ar/5% O_2, Ar/5% CO_2, and TIME 2 gas. These 33 welds were radiographed for soundness. The Ar/5% O_2 and TIME 2 welds had very slight porosity (level G1 fine scattered porosity as per ASTM E390) at wire feed rates of up to 1800 ipm. At 2000 ipm, however, both gases had unacceptable levels of porosity (level G5 elongated clustered porosity as per ASTM E390). The Ar/5% CO_2 welds exhibited similar porosity except that the welds made at 1600 and 2000 ipm had level G5 porosity (but 1800 ipm had level G1).

It was found that cold lap was a problem for nonpreheated plates whenever the wire feed rate was greater than 1200 ipm. A number of problems were also encountered with lack of fusion and irregular bead appearance when groove welds were made on the mechanical test specimens. Also, it became apparent that lack of shielding gas coverage of the high temperature weld bead is a problem at high wire feed rates and that a trailing shield gas cover is required. Because of the problems and the extensive time required to machine specimens from the 53 Rc base material, mechanical property determination results are not available at this time.

The shielding gas composition has a large effect on the weld current obtained for a given wire feed rate, voltage, and stickout. Figure 31 illustrates this effect for three gases. As can be seen, the current required for a given wire feed rate is lower for gas mixtures of argon/helium; namely, that more helium decreases the current required for a given wire feed rate, voltage, and stickout. It was also found that increasing the oxygen activity in the arc atmosphere increases the required current.

DISCUSSION

When all other welding conditions are kept constant, and the wire feed rate gradually increased, the metal transfer mode will change from short circuiting, to globular, to spray, to rotational (not all gases will exhibit all of these modes). In general, the transition from short circuiting globular and from globular to spray is at a well-defined current (or wire feed rate) and is easily distinguished. However, at higher feed rates, the mode changes from spray to either unstable spray, unstable rotational, "quasi-stable rotational," or rotational. This transition is not always readily distinguishable.

For example, for a gas composition of 95% Ar/5% O_2, a 1-3/16" tip-to-work distance (Figure 1), and 25 volts, the metal transfer mode will change from stable axial spray (with the classic bell-shaped arc and very smooth small droplet transfer) to stable spray with intermittent fluctuations. The intermittent fluctuations appear to be short circuiting transfer due to the high feed rate forcing the electrode into the weld pool before completely melting. The fluctuations do not appear to be due to oxide buildup or any other form of electrode contamination. As the feed rate is increased, the fluctuations appear more frequently with a corresponding increase in spatter, until the transfer becomes completely unstable with no rotational transfer ever occurring.

If the voltage in the previous example (Figure 1) is increased to 40 volts, the arc length is increased substantially. In this case, the metal transfer will go from stable spray to spray without the classic bell-shaped arc to a quasi-stable rotational transfer as the wire feed rate is increased. Since the arc length is longer, no intermittent short circuiting will occur.

Although it is known that the metal transfer mode will transfer from spray to rotational, there is little information on the nature of this transition. Whereas the globular-to-spray transition is sudden, the spray-to-rotational (or unstable spray) transition is quite gradual. Thus, the regions labeled as "spray" in the figures represent welding conditions which result in a very stable axial spray with no intermittent fluctuations or spatter. It is possible to make sound weld deposits in the rotational region without arc instability, however, there may also be a higher risk of welding defects.

In the present research, the globular, spray, and rotational regions were mapped out for seven different gas mixtures. The uncertainty, or error bars, for all of the data in Figures 1 through 20 is approximately $\pm$ 50 ipm.

The globular-to-spray transition occurs for all gas, nozzle, and stickout combinations at about the same wire feed rate. The addition of helium, or use of lower stickout, can increase this slightly at higher voltages, but not significantly.

The spray-to-rotation transition varies much more as a function of gas and stickout. Actually, the transition will usually be from spray to unstable spray (spray with occasional "fluttering" or radical changes in arc length), then unstable spray to unstable rotational (rotating arc with occasional long arc length spray transfer), then unstable rotation-to-stable rotation, and finally stable rotation to a different type of unstable rotation (rotating arc with occasional short circuiting). These regions are schematically illustrated in Figure 30. However, since these various high current transitions are so subtle, and vary as a function of voltage, gas, base metal, filler metal, joint geometry, and stickout, this research has only mapped out the spray to "nonspray" (hereafter referred to as rotational) metal transfer transition.

Normally, the spray-to-rotational transition current is not exceeded because spray transfer is very stable, quiet, and defect free. However, welding in the rotation transfer mode, often referred to as high current density (HCD), can allow the use of much greater deposition rates.

At the 1-3/16" stickout, the argon/oxygen gas mixtures had the lowest spray rotational transition. The Ar/2% O_2 only maintained a spray transfer until 600 ipm. The Ar/5% O_2 add a lower transition, but was the only gas able to maintain a spray at 25 volts. The use of 95% Ar/5% CO_2 increased the transition substantially over the 95% Ar/5% O_2.

The addition of helium to either Ar/O_2, Ar/CO_2, or Ar/O_2/CO_2 mixtures increases the spray rotational transition as shown in Figures 4 through 7. The TIME 2 gas exhibited the highest transition feed rate of almost 1000 ipm at 40 volts, but became very unstable at 44 volts. The 65% Ar/25% He/10% CO_2 mixture appeared to be the most stable, and voltage variation had little effect on the transition feed rate of 800 ipm.

The use of the TIME torch, shown in Figures 8 through 15, seemed to have little effect at this stickout with two exceptions. The TIME torch stabilized the TIME 2 gas at 44 volts, thus providing the highest spray deposition rates at this stickout. However, the engineers at GD had difficulty reproducing this effect. Also, the TIME torch allowed much higher spray feed rates for 95% Ar/5% O_2, but sacrificed the ability to spray at lower voltages. The use of the TIME torch in production conditions has also resulted in some cases of excess porosity.

The use of lower stickouts (3/4") was evaluated for three gases and both torches. With the standard torch, lower stickouts increased the range of spraying conditions for Ar/O_2 and Ar/CO_2, but slightly decreased the range for both TIME 1 and TIME 2 gases. The TIME torch had virtually no effect or an adverse affect on the spray-to-rotational transition at the lower stickout.

Throughout this study, the effect of gas composition on transition wire feed rates for the various modes of metal transfer were evaluated. Normally, transition currents are discussed in the literature. The reason for the use of wire feed rates in this study is because we are primarily interested in maximizing the allowable deposition rate and the enduring cost savings. Maximizing the transition current can give a misleading impression. For example, the spray-to-rotational transition current at 40 volts and 1-3/16" stickout is about 340 amps for Ar/5% O_2, and 330 amps for Ar/5% CO_2. The higher transition current of Ar/5% O_2 does not correlate with the higher transition wire feed rate of Ar/5% CO_2.

The amount of diffusible hydrogen was found to vary substantially with the gas and base metal composition. Figure 21 shows that welds made with pure argon have the lowest amount of hydrogen. Figures 22 and 23 show that adding 2 to 10% CO_2 increases the amount of hydrogen, and that adding 2 to 5% O_2 increases the amount of hydrogen even more. Figure 24 shows that adding helium increases the amount of hydrogen most of all.

Previous research by Gedeon[5] has shown, through the use of Fe-C-H-O phase diagrams, that hydrogen is more readily absorbed by the weld pool when combined with oxygen in the arc atmosphere to form H_2O. In other words, H_2O is more readily absorbed than H_2 due to the high affirmity of liquid iron for oxygen. Carbon dioxide (CO_2) will break down in the high temperature region of the arc into CO + O_2. There will then be partial pressures of H_2O, O_2, CO, and H_2. The H_2O will be absorbed more readily than the H_2; thus, welds made with CO_2 gas mixtures will absorb less hydrogen than those made with O_2 mixtures.

Helium increases the arc plasma temperature and decreases arc stability. It is postulated that the more violent action of the weld pool exposes more weld pool-free surface to the hydrogen-containing arc atmosphere, thus increasing the absorbed hydrogen. It is also possible that the increased temperature of the arc plasma results in more monatomic hydrogen available to strike the weld pool surface. (Monatomic hydrogen is absorbed more readily than diatomic hydrogen.[5])

The primary question remaining is "What is the maximum allowable wire feed rate?" This is a complicated question and the answer will depend on the specific application.

If spray transfer is desired, then this study has shown exactly how the maximum wire feed rate depends on gas composition. Since the helium containing gases absorbed so much hydrogen, the optimum gas to use should be either Ar/O_2 or Ar/CO_2. Of these, the Ar/5% CO_2 absorbs the least hydrogen, and can operate at the highest wire feed rate.

If rotational metal transfer is desired, then the data from this study is not complete. Each gas has a number of regions that were not completely mapped out in the study. Figure 30 shows an example of what this map would look like. As can be seen, the arc will be unstable immediately above the spray to rotational transition and then become stable at higher currents (feed rates).

If the "unstable zone" above the spray-to-rotation transition current is assumed to be a constant 300 ipm, then Ar/5% O_2 will be stable for rotational transfer at 1000 ipm (because 300 plus the transition value of 600 is less than 1000) whereas Ar/5% CO_2 will be unstable at 1000 ipm (but stable at 1200 ipm).

However, once the wire feed rate begins to approach these high values, the ballistic integrity may become compromised. There will undoubtedly be some maximum heat input limitation for the quench-and-tempered armor steels used in M1 production. General Dynamics has ballistically qualified up to 85 kJ/in. weld heat inputs. Since this question has only recently come up, there is little data to show what the maximum allowable heat input is. This question has been addressed for the HY series steels, and must now be researched for the armor steels used by the U.S. Army.

Another consideration is that the rotational transfer may "bump" into the sides of groove and fillet welds during production and cause weld irregularities and defects. Also, the use of a trailing shield gas may be needed for these higher heat inputs.

There may be better ways of increasing deposition rate (and thus productivity). A weave technique may prove worthwhile, as may higher diameter filler metals. These questions should be addressed in a future study.

5. GEDEON, S. A. *Hydrogen Assisted Cracking of High Strength Steel Welds.* U. S. Army Materials Technology Laboratory, MTL TR 88-11, May 1988.

SUMMARY

The globular, spray, and rotational metal transfer regions were mapped as a function of wire feed rate and voltage. This was performed for seven gas mixtures at two stickouts (contact tip-to-work distance) and two nozzle geometries.

For large stickouts (1-3/16"), gas mixtures containing 25-35% helium were able to maintain a stable axial spray transfer for bead-on-plate welds at the highest wire feed rates. This amounts to deposition rates of about 23 pounds per hour (with 0.045"-diameter electrodes). Ar/5% O2 was able to spray at the widest range of voltages, but at much lower wire feed rates.

The patented TIME torch nozzle slightly increased the maximum spray wire feed rates for a few gases at high stickouts but had no effect or an adverse affect at lower stickouts.

Welds made with the Ar/2-10% CO_2 gas mixtures absorb the least amount of hydrogen. Welds made with Ar/2-5% O_2 absorb slightly more. The TIME gas results in welds with approximately twice the amount of diffusible weld hydrogen. The greater weld hydrogen contents of the TIME gas welds could potentially result in hydrogen cracking problems. The addition of helium is responsible for the large amount of absorbed hydrogen.

The results of this project show that a number of lower cost gases exist which are as good or better than the TIME gas. General Dynamics has performed mechanical and ballistic tests using Ar/5% O_2, TIME (Ar/He/CO_2/O_2), and STARGON (Ar/CO_2/O_2), and has taken steps to use 95% Ar/5% O_2 throughout their entire facility.* This will amount to an estimated cost savings of approximately $1 million per year,† which is documented in the Appendix.

Bead profiles were examined as a function of transfer made and shielding gas composition. During rotational transfer, helium causes deeper finger-like penetration, and Ar/5% CO_2 had a well-rounded bead profile. During spray transfer, the penetration did not vary, but helium caused a more well-rounded profile (as is reported in the literature). During the globular transfer, the helium acts to promote finger-like penetration and increase penetration. These effects have never before been documented and are not understood at this time.

Bead-on-plate welds were made with rotational transfer at wire feed rates of up to 2000 ipm. Radiography showed that level G5 clustered porosity can occur at rates of over 1600 ipm for all of the gas mixtures tested. However, the ability to make sound groove or fillet welds remains to be determined. Another consideration for the very high current welds is that trailing shield gas coverage is required.

The maximum possible deposition rate allowable for armor steel welding is still unknown at this time. Future work should address this issue based on the findings of the present study.

RECOMMENDATIONS

1. Due to the lower cost and high performance of Ar/O_2 and Ar/CO_2 gas mixtures, it is recommended that the General Dynamics proposal to replace TIME gas with Ar/5% O_2 be approved.

2. TIME gas and other helium-containing shield gases may not be a good choice for welding armor steel due to the potentially large amount of absorbed hydrogen that they promote.

3. Of the gases studied, Ar/5% CO_2 appears to be the best choice of shielding gas for welding with spray transfer, as determined by the low absorbed hydrogen and high wire feed rate. The optimum gas for welding with rotational metal transfer has not been determined.

4. A further study should be performed to determine the maximum acceptable weld heat input and wire feed rate for rotational transfer. This future study will need to assess production factors which may limit the use of rotational metal transfer.

* Personal communication with J. L. Sherman, General Dynamics Land Systems Division, August 1987.
† Personal communication with F. Ade, General Dynamics Land Systems Division, September 1987.

ACKNOWLEDGMENTS

Acknowledgment is given to the U.S. Army Tank-Automotive Command (TACOM), Value Engineering (VE) program, for providing the funding for this project. Special thanks to Frank Wong and Art White in the VE office for helping to make things run smoothly. Thanks also to Terry Dean of the M1 Program Manager's office for aiding the initial justification of this project.

Special thanks to all those at MTL who helped with various facets of this project: Tom Harkins (radiography), Atillio Santoro (welding), and Donald Hassett (welding).

The engineers at General Dynamics also helped freely with advice and data. In particular, we would like to thank Fred Ade for his help and advice. With this phase of the project concluded, we will work more closely than ever on the logical extension of these results.

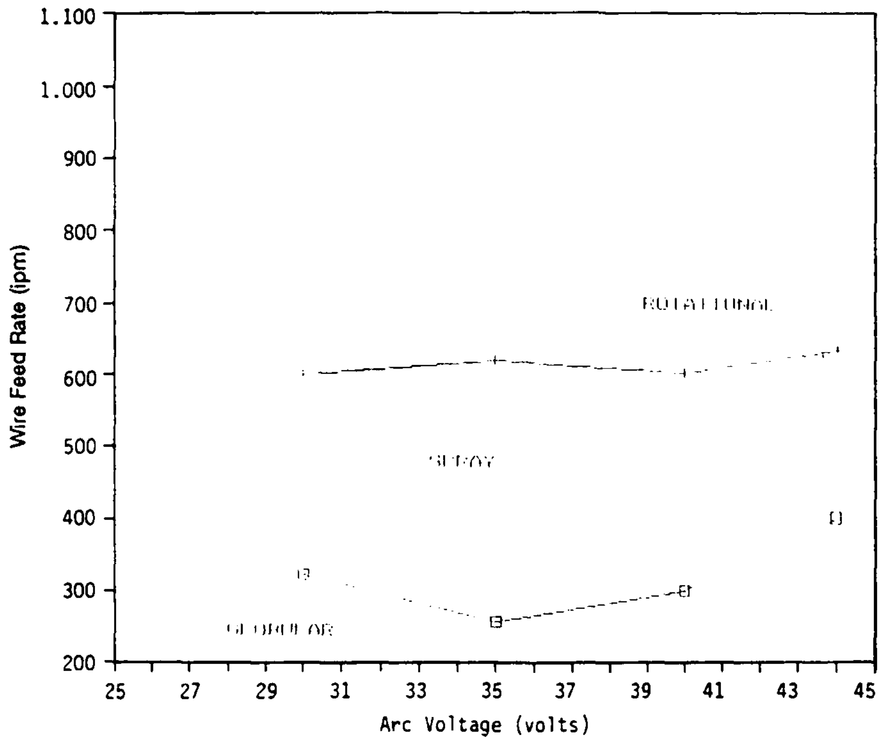

Figure 1. Metal transfer regions for 98% Ar/2% O_2 (standard torch, 1-3/16" stickout).

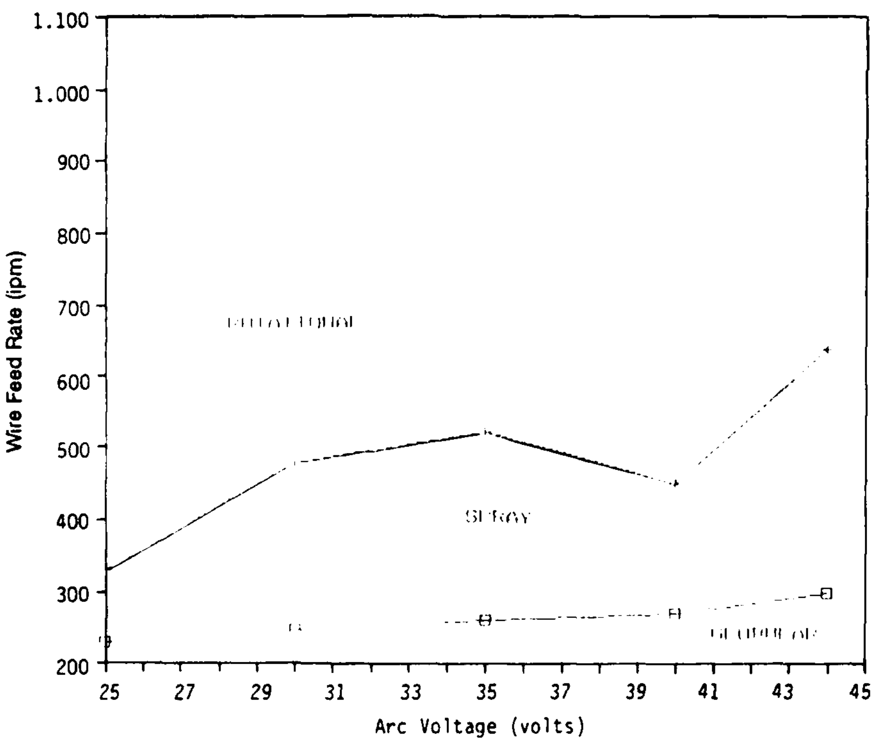

Figure 2. Metal transfer regions for 95% Ar/5% O_2 (standard torch, 1-3/16" stickout).

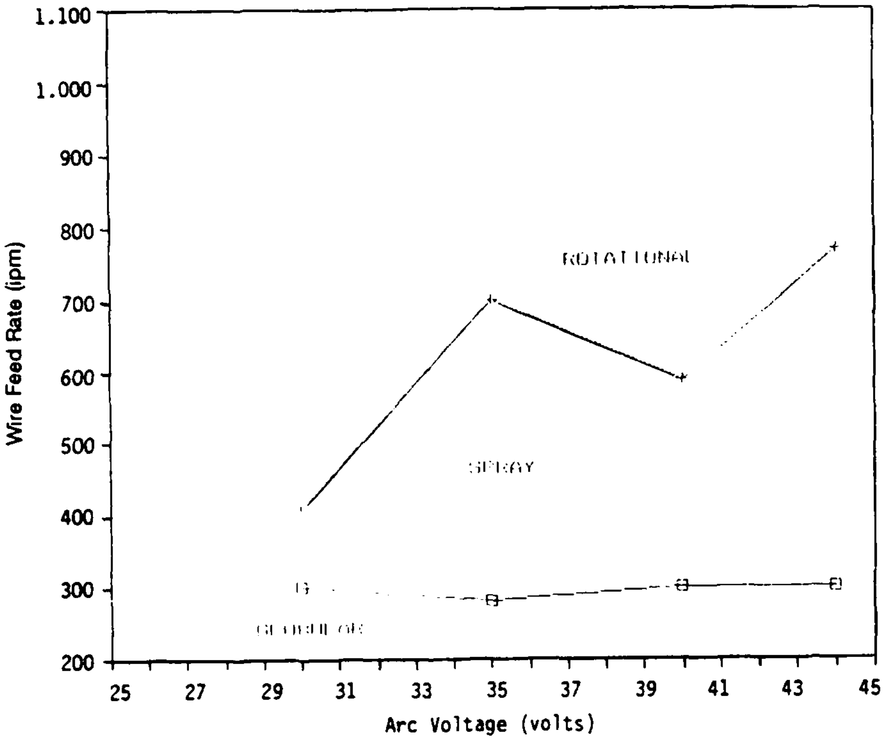

Figure 3. Metal transfer regions for 95% Ar/5% CO_2 (standard torch, 1-3/16" stickout).

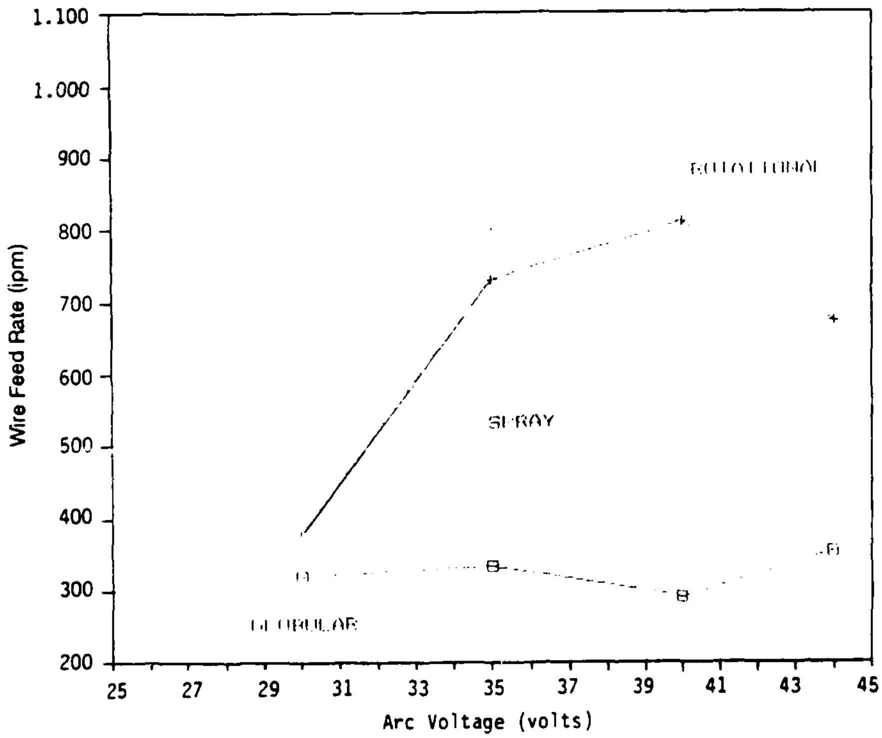

Figure 4. Metal transfer regions for 70% Ar/25% He/5% CO_2 (standard torch, 1-3/16" stickout).

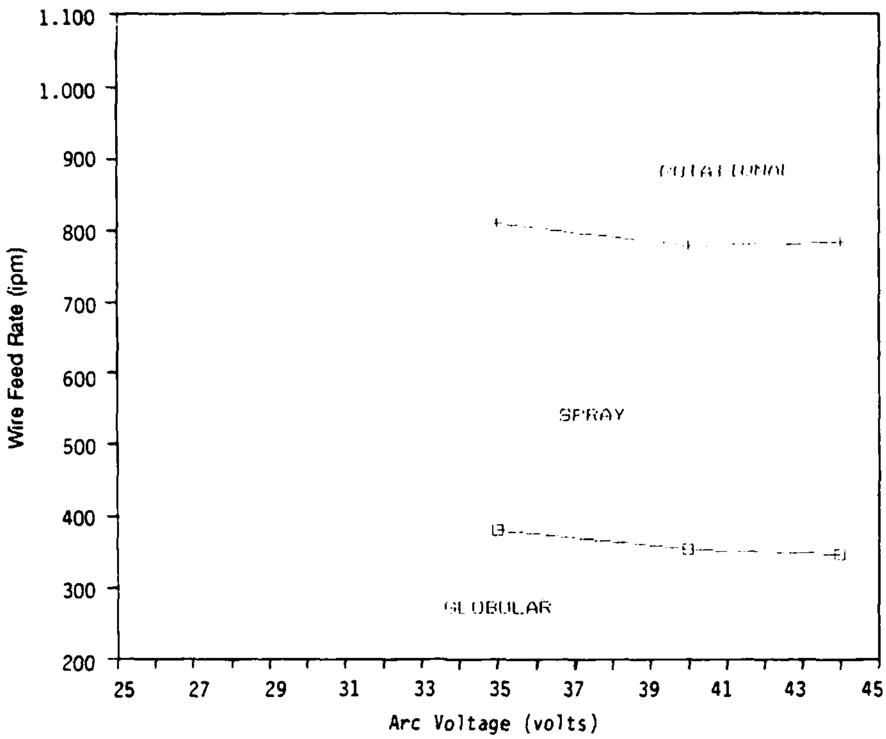

Figure 5. Metal transfer regions for 65% Ar/25% He/10% CO_2
(standard torch, 1-3/16" stickout).

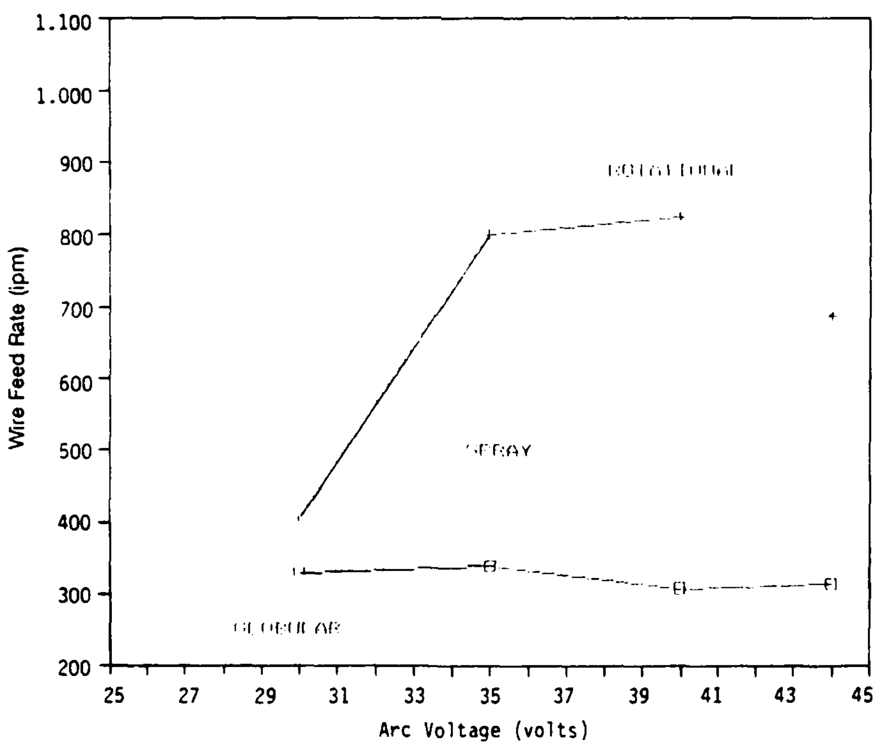

Figure 6. Metal transfer regions for TIME 1
(standard torch, 1-3/16" stickout).

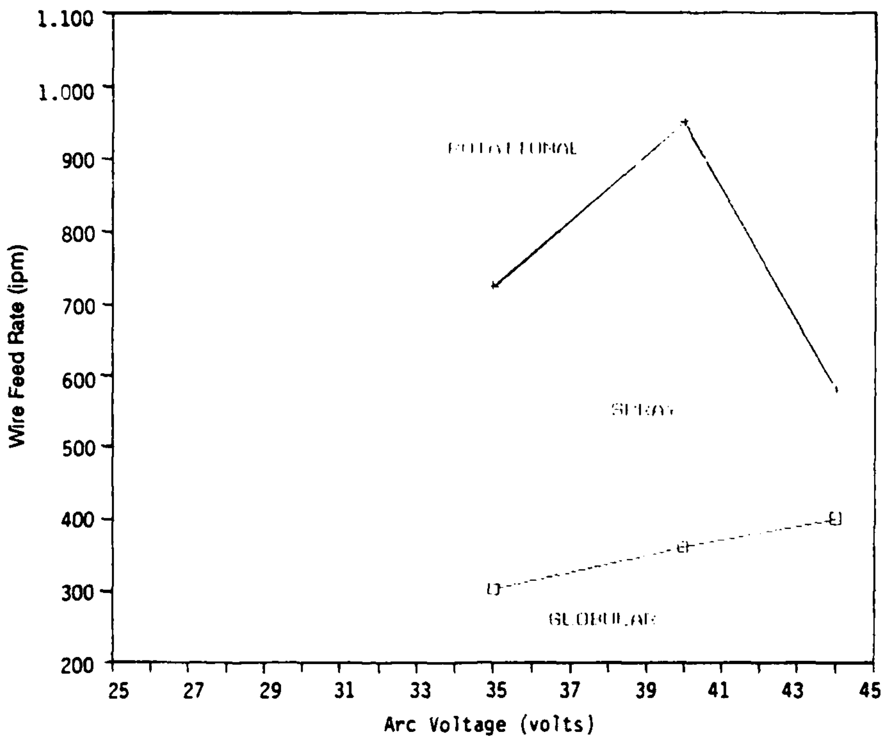

Figure 7. Metal transfer regions for TIME 2
(standard torch, 1-3/16" stickout).

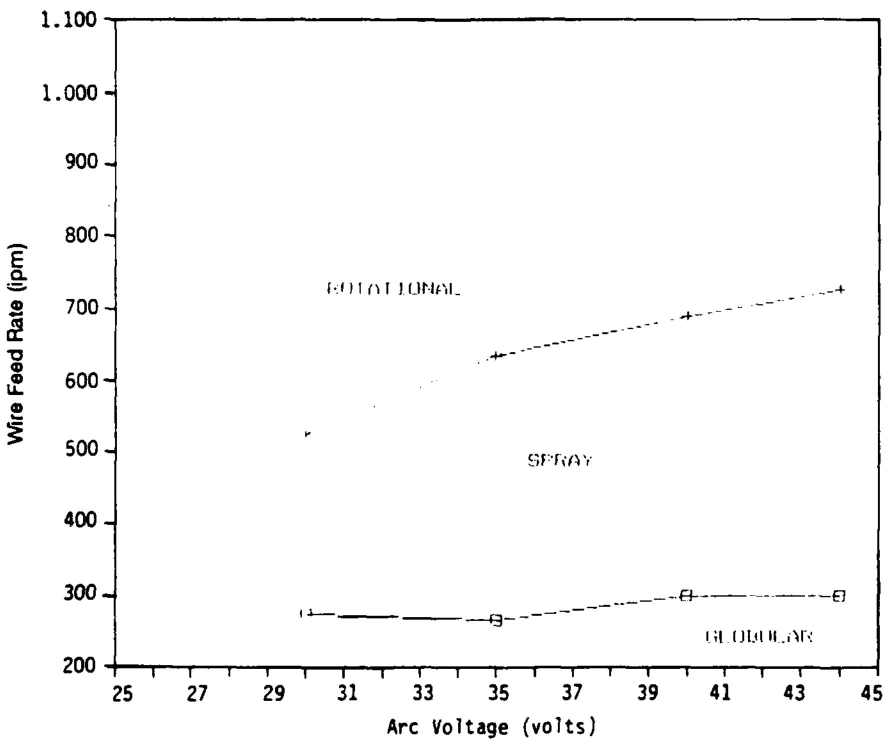

Figure 8. Metal transfer regions for 98% Ar/2% O_2
(TIME torch, 1-3/16" stickout).

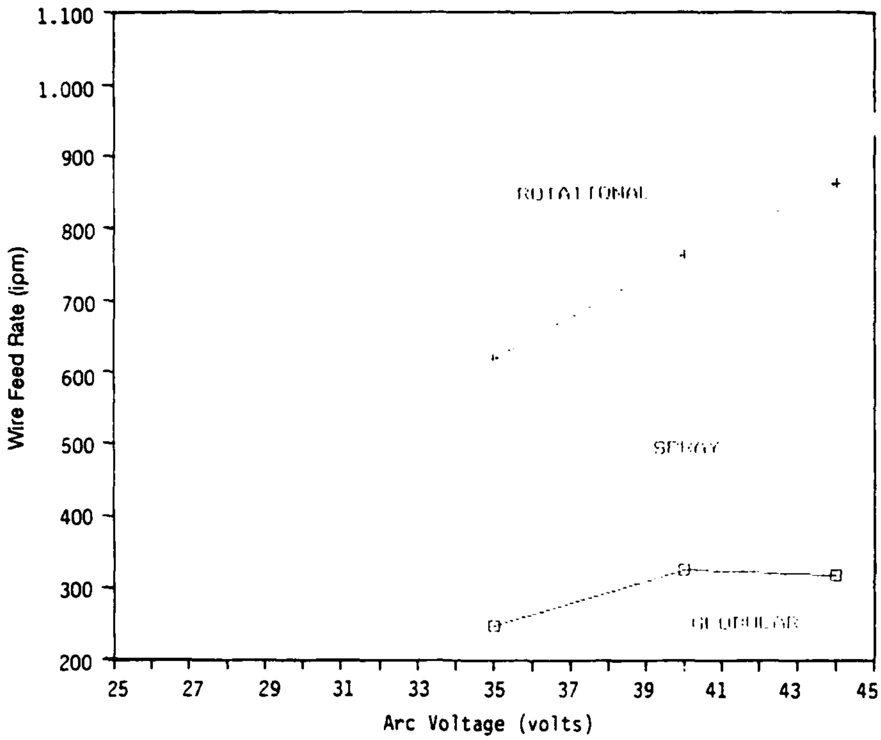

Figure 9. Metal transfer regions for 95% Ar/5% O_2
(TIME torch, 1-3/16" stickout).

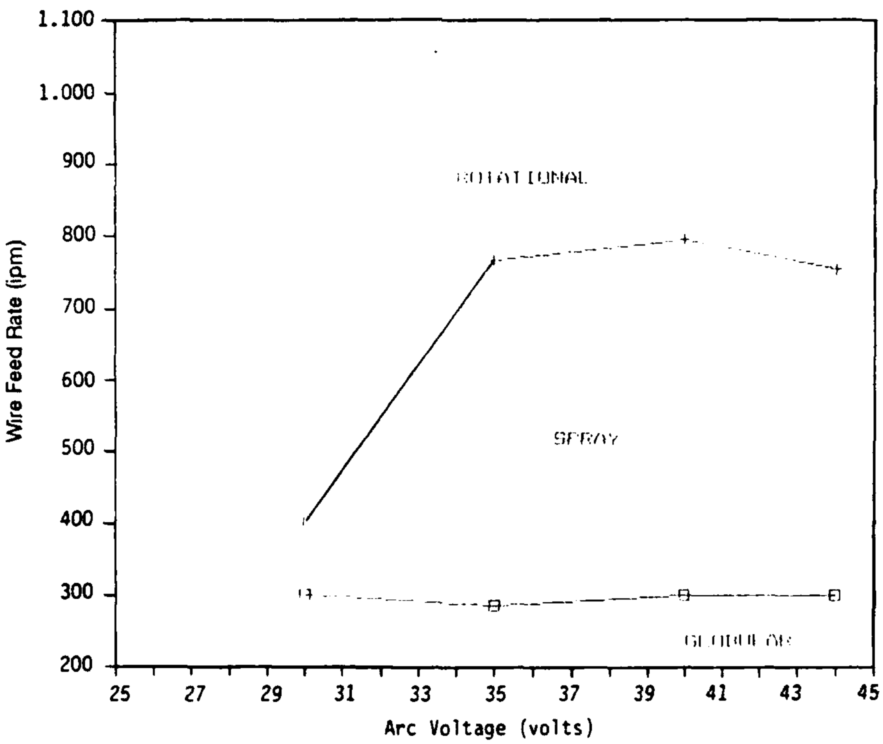

Figure 10. Metal transfer regions for 95% Ar/5% CO_2
(TIME torch, 1-3/16" stickout).

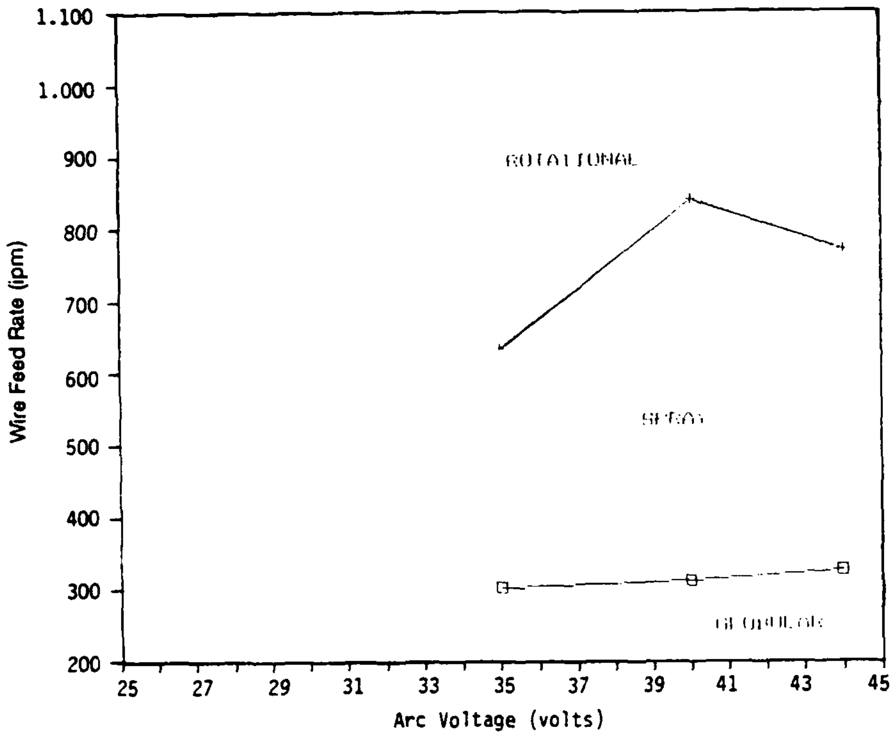

Figure 11. Metal transfer regions for 70% Ar/25% He/5% CO_2
(TIME torch, 1-3/16" stickout).

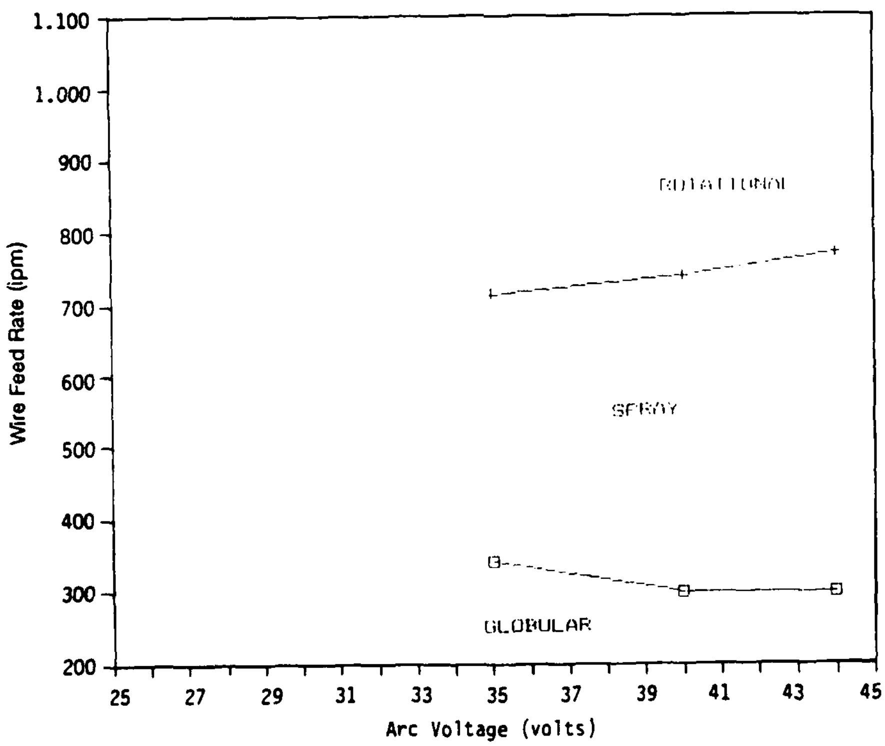

Figure 12. Metal transfer regions for 70% Ar/25% He/10% CO_2
(TIME torch, 1-3/16" stickout).

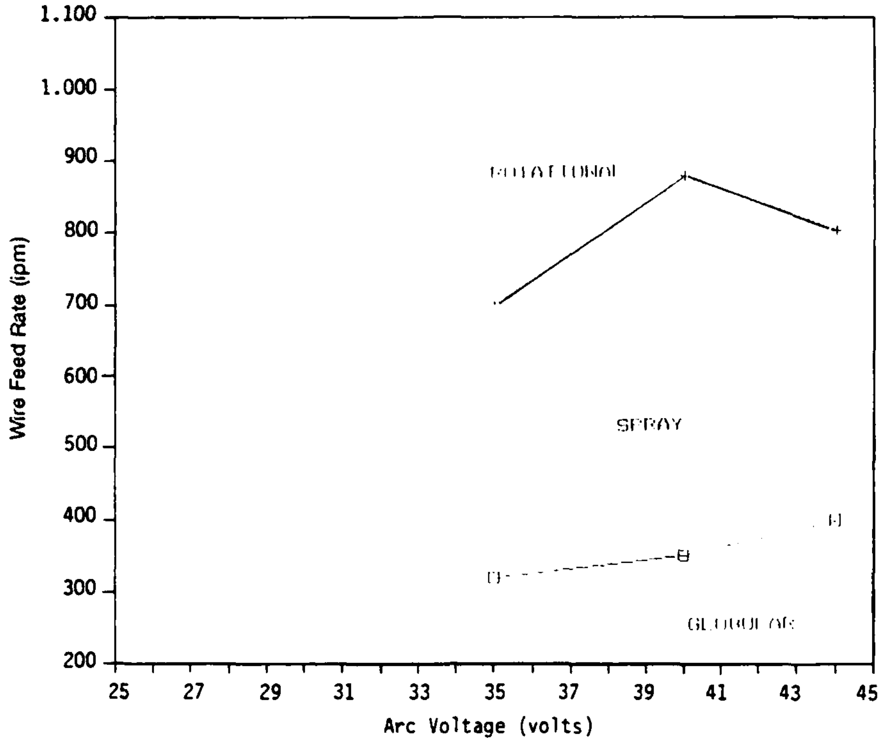

Figure 13. Metal transfer regions for TIME 1
(TIME torch, 1-3/16" stickout).

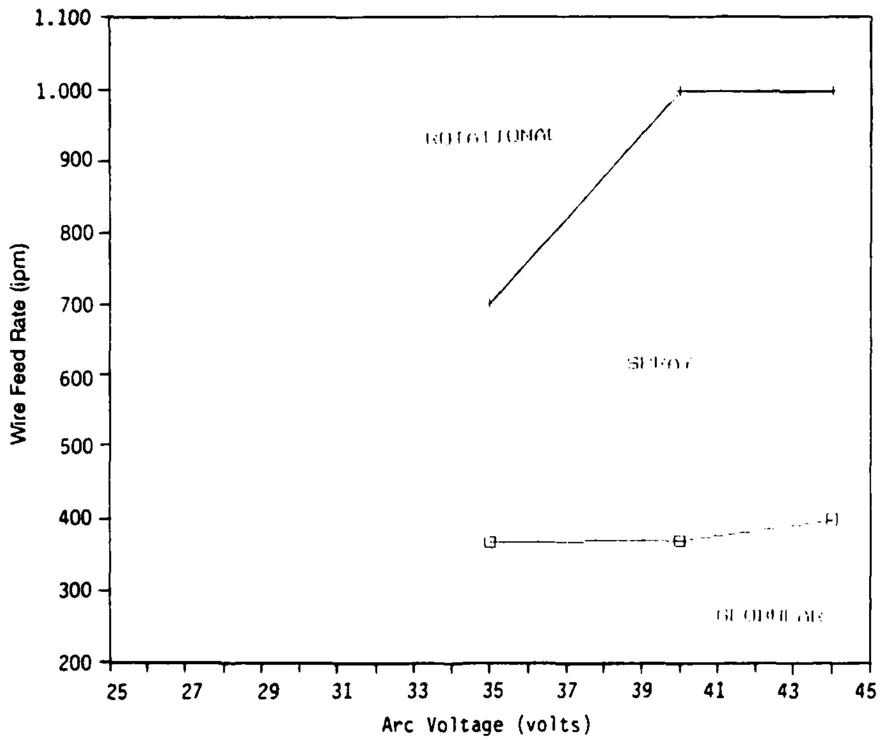

Figure 14. Metal transfer regions for TIME 2
(TIME torch, 1-3/16" stickout).

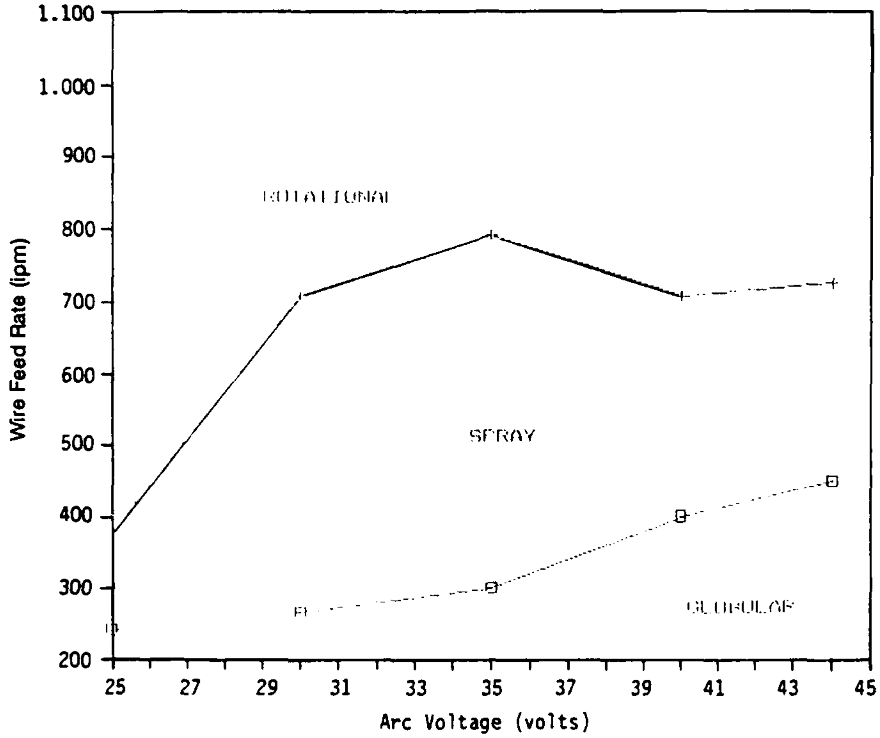

Figure 15. Metal transfer regions for 95% Ar/5% O_2 (standard torch, 3/4" stickout).

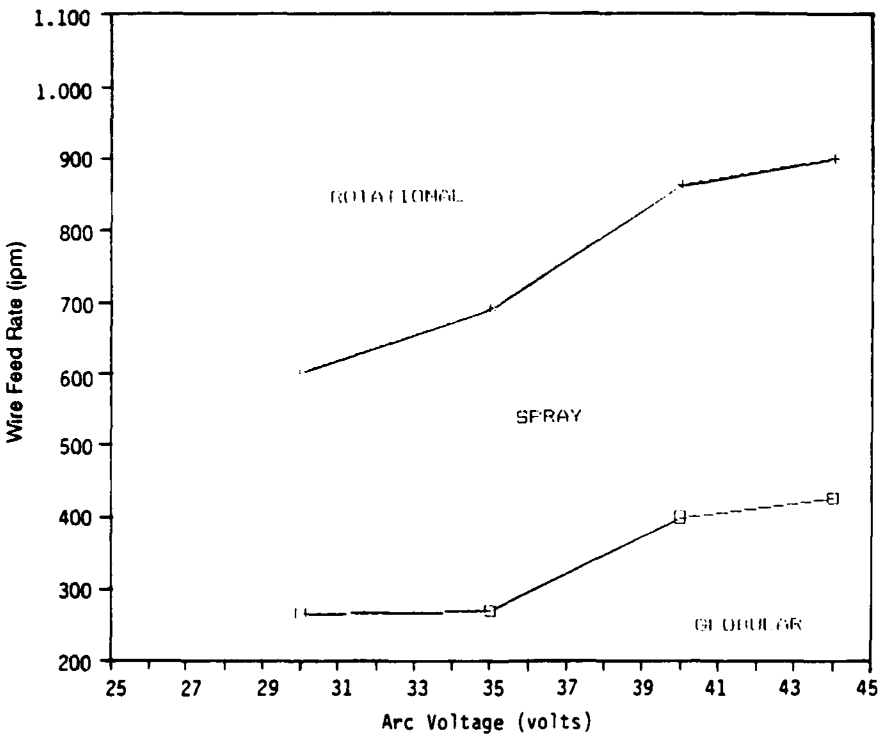

Figure 16. Metal transfer regions for 95% Ar/5% CO_2 (standard torch, 3/4" stickout).

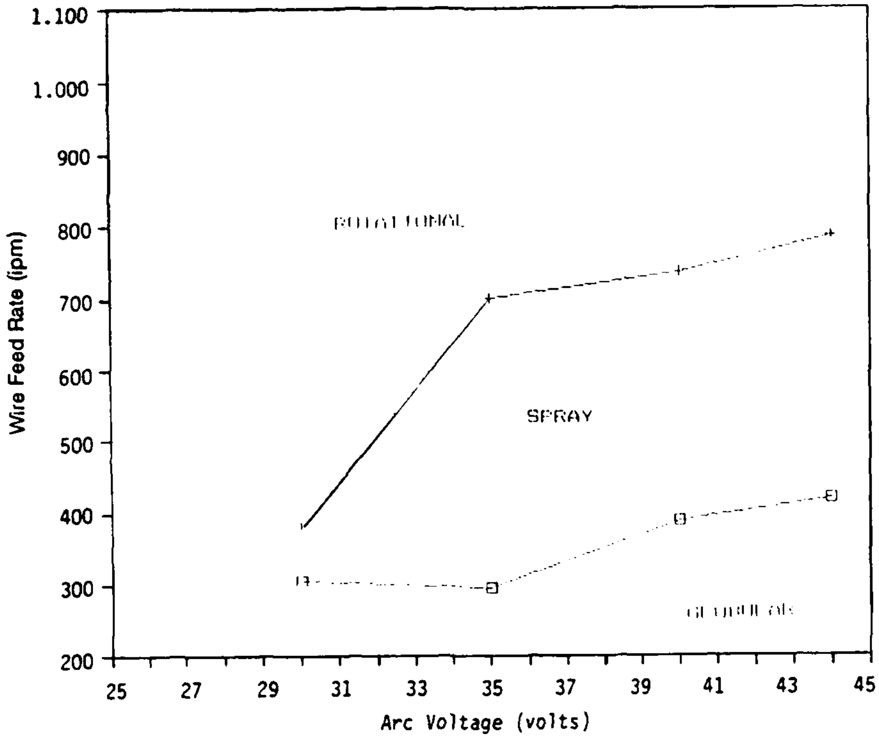

Figure 17. Metal transfer regions for TIME 2
(standard torch, 3/4" stickout).

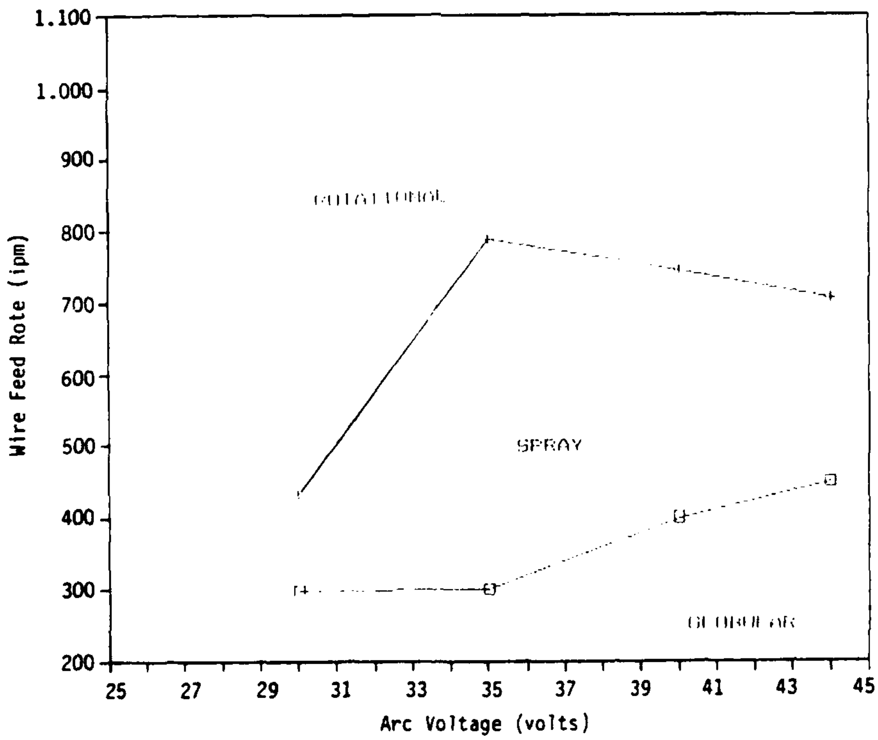

Figure 18. Metal transfer regions for 95% Ar/5% O_2
(TIME torch, 3/4" stickout).

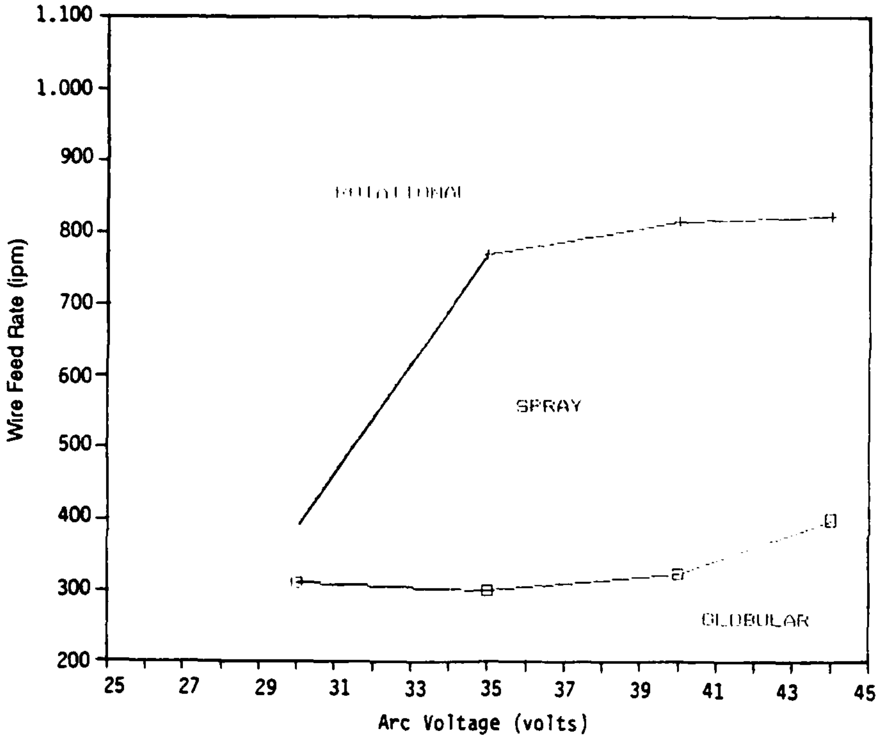

Figure 19. Metal transfer regions for 95% Ar/5% CO_2
(TIME torch, 3/4" stickout).

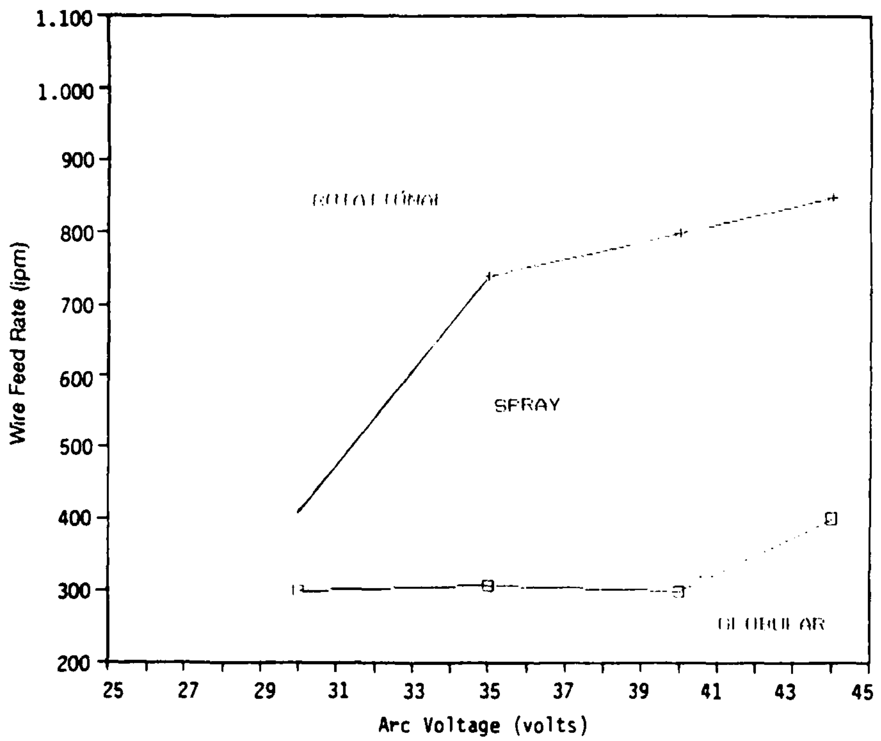

Figure 20. Metal transfer regions for TIME 2
(TIME torch, 3/4" stickout).

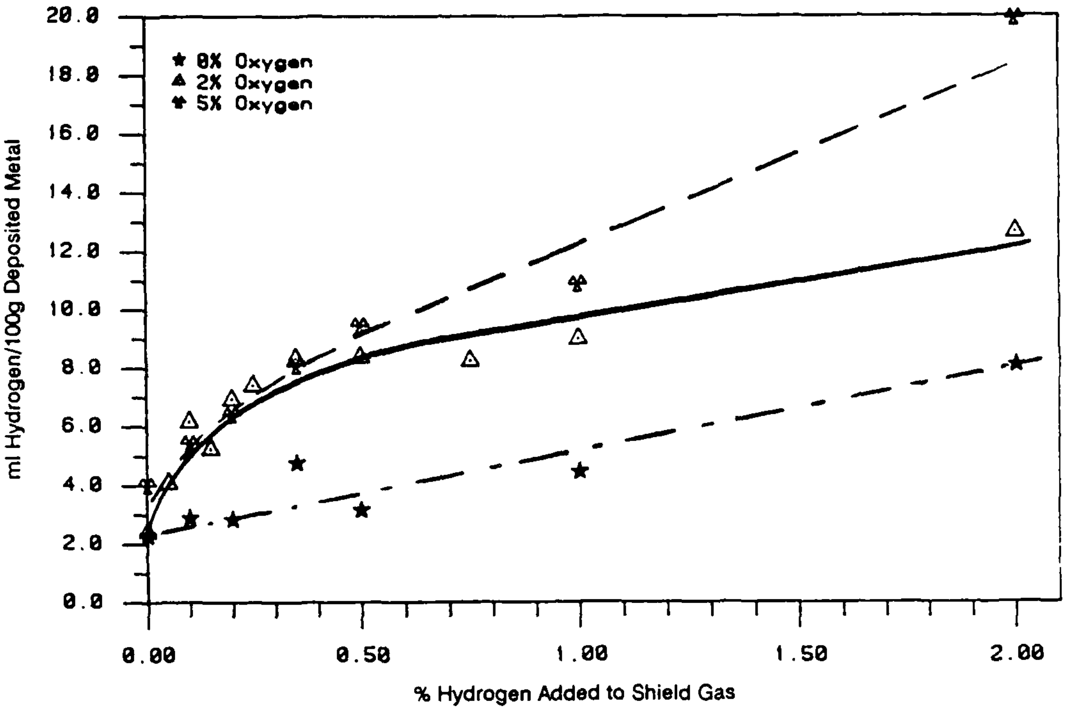

Figure 21. Diffusible hydrogen as a function of hydrogen in the GMAW shielding gas. *Curves depict Ar with 0%, 2%, and 5% oxygen (A36, AWS).*

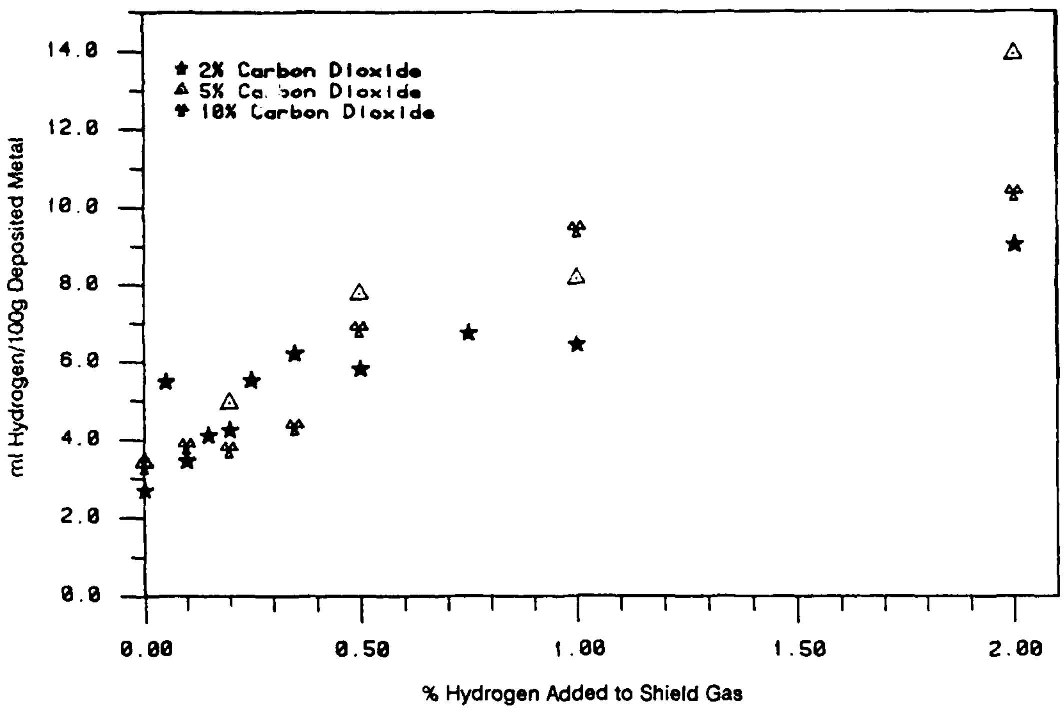

Figure 22. Diffusible hydrogen as a function of percent hydrogen in a shielding gas with different amounts of carbon dioxide in argon (A36, AWS).

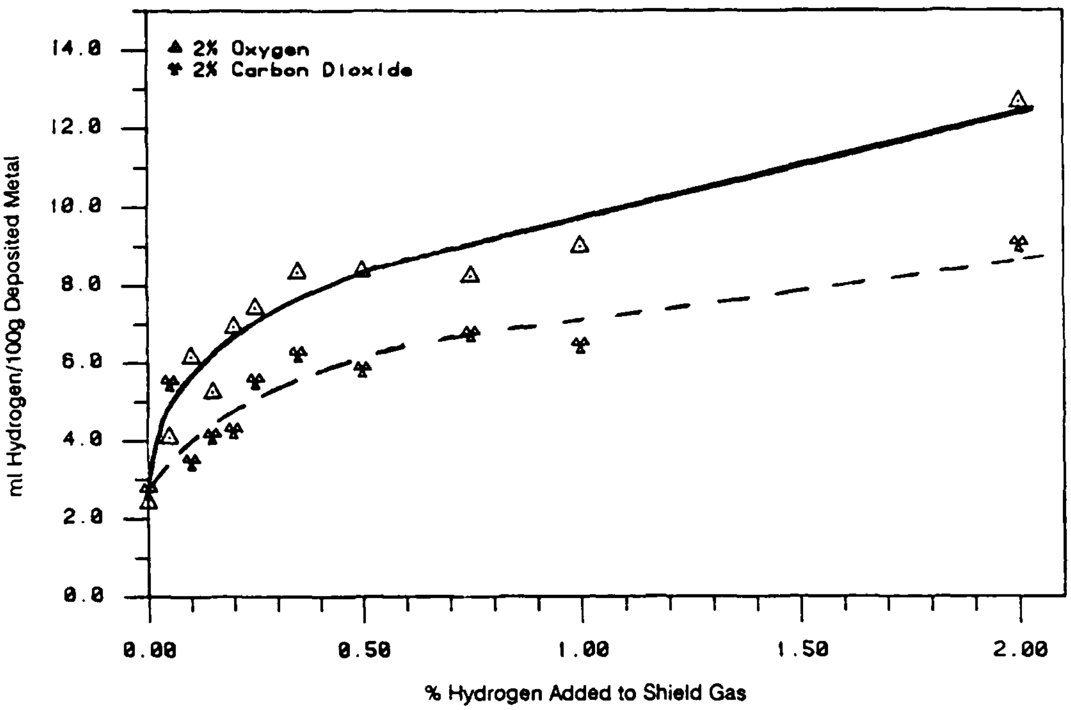

Figure 23. Comparison of the effect of 2% oxygen and 2% carbon dioxide in the shielding gas (A36, AWS).

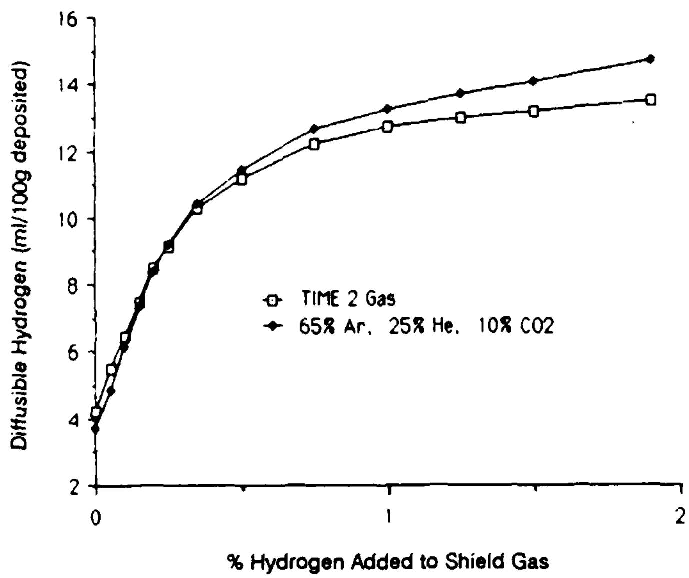

Figure 24. Diffusible hydrogen content for TIME gas and 65% Ar/25% He/10% CO_2 welds.

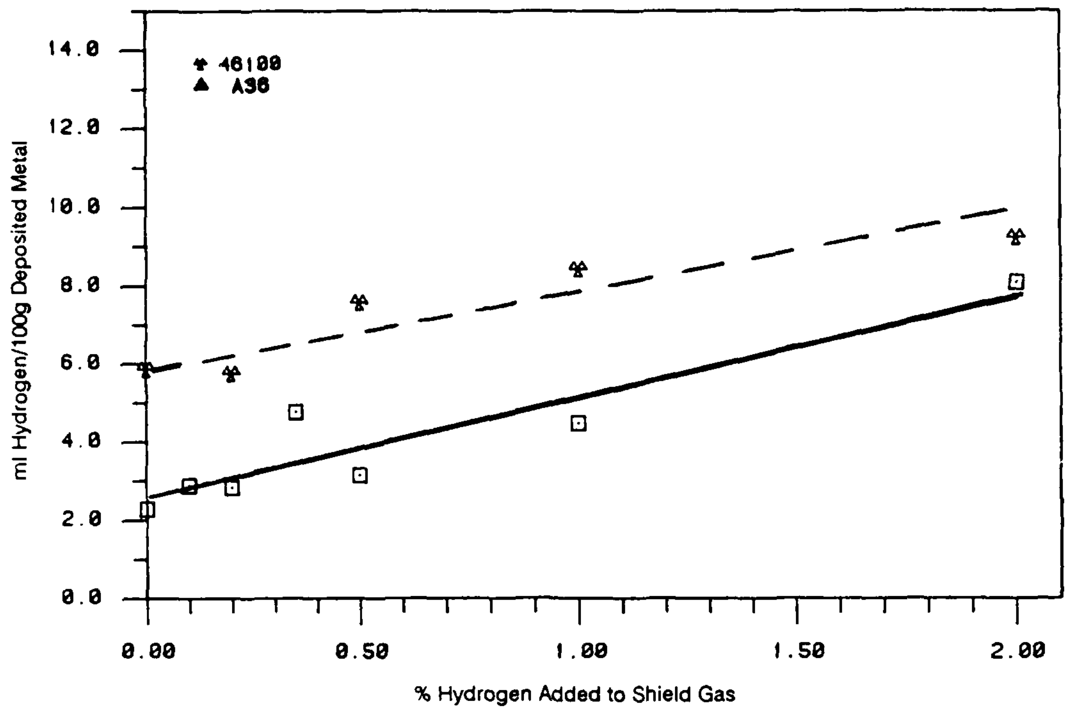

Figure 25. Diffusible hydrogen versus hydrogen in pure argon shielding gas for A36 and 46100 steel.

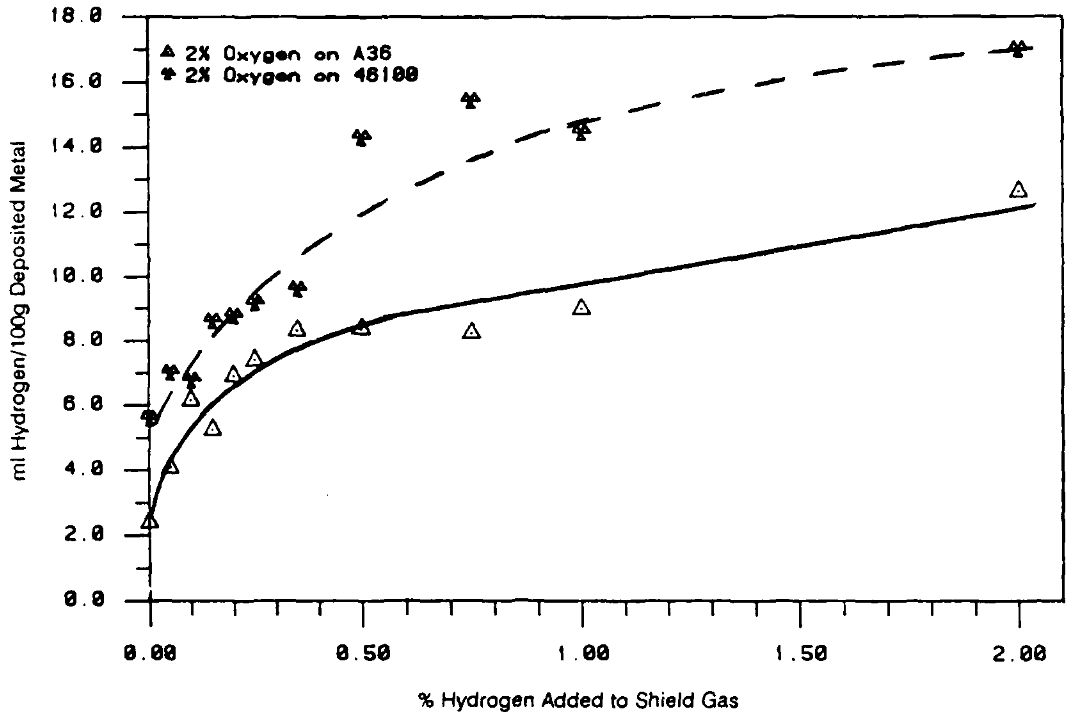

Figure 26. Diffusible hydrogen versus hydrogen in Ar/2% O_2 shielding gas for A36 and 46100 steel.

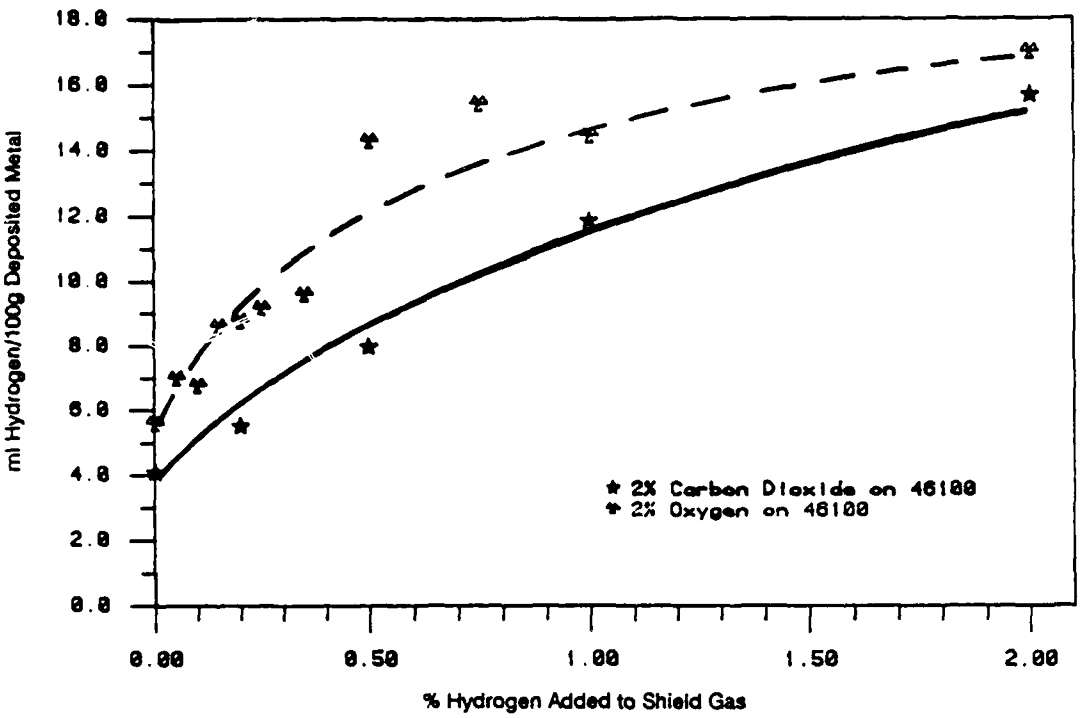

Figure 27. Diffusible hydrogen content of 46100 versus hydrogen in the shielding gas for Ar/2% O_2 and Ar/2% CO_2.

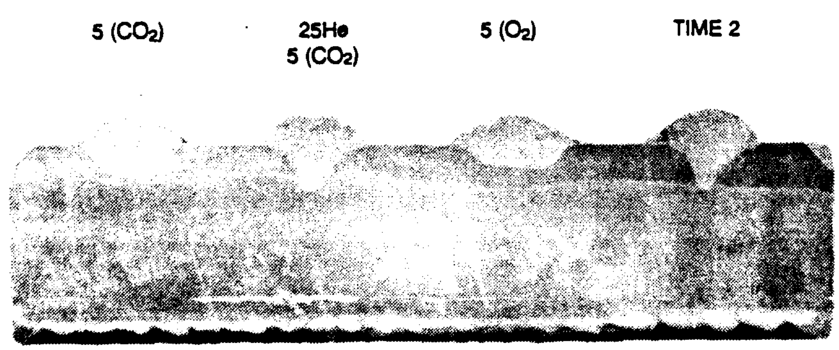

Figure 28. Weld bead profiles showing the effect of gas composition during rotational metal transfer (1000 ipm wire feed rate, 40V, 1-3/16" stickout, heat input held at 9.5 kJ/in.).

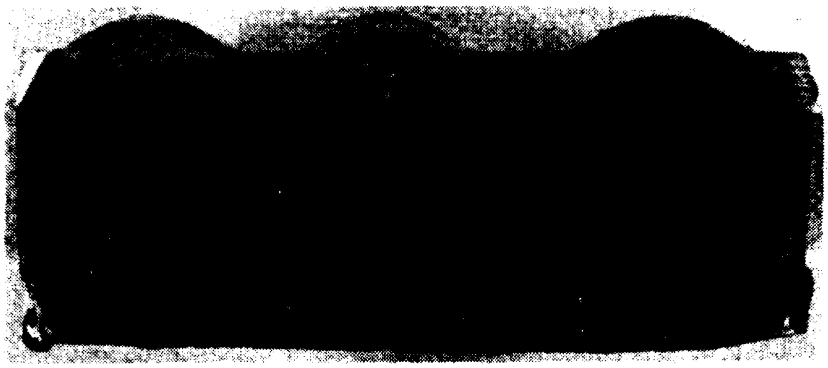

Figure 29. Weld bead profiles of spray transfer welds (400 ipm wire feed rate, 32V, 1" stickout, heat input held at 9.5 kJ/in.).

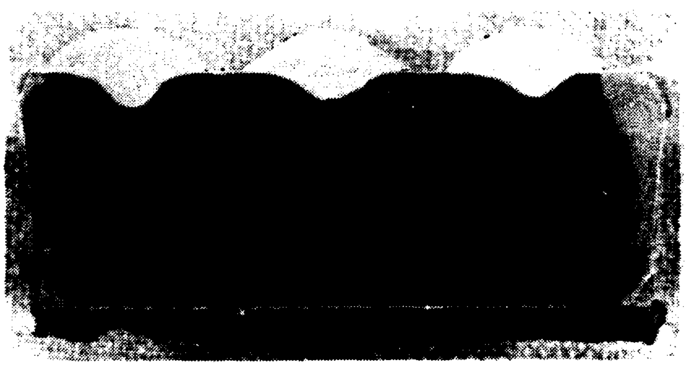

Figure 30. Weld bead profile of globular transfer welds (230 ipm wire feed rate, 24V, 3/4" stickout, heat input held at 9.5 kJ/in.).

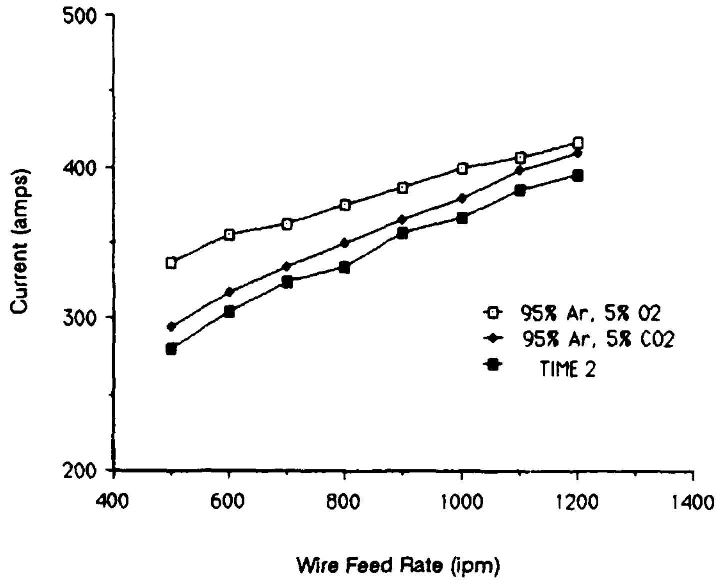

Figure 31. The effect of gas composition on the current as a function of wire feed rate (40V, 28 ipm travel speed, 1-3/16" stickout).

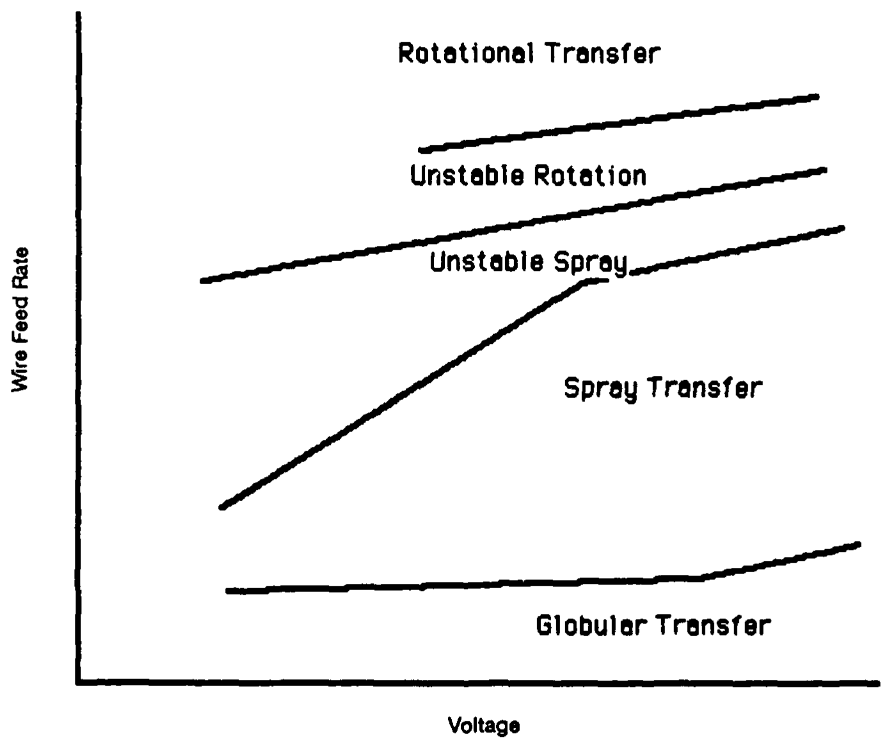

Figure 32. Schematic diagram of unstable regions.

APPENDIX. VALUE ENGINEERING STUDY REPORT (VESTU 86-GCM-127)

1. Title: Reduce Weld Fabrication Cost

2. System Effected:

M1 Series Tank

3. Present System:

The Transferred Ionized Molten Energy (TIME) gas, a patented Canadian welding gas/nozzle combination, is being used extensively in the welding of the M1A1 hull and turret structures at the LATP. The gas has been claimed to allow much greater weld deposition rates than previously used gasses. In addition, welds produced using this gas have shown acceptable weld quality and ballistic performance. The basic composition of TIME gas consists of a primary 4-part gas mix of 66 percent AR, 25.5 percent HE, 8 percent CO_2 and 0.5 percent O_2. The only draw back in using this gas mixture is that the U.S. Army is being forced to pay an exorbitant fee for a patented welding gas manufactured in Canada. Similar gases manufactured in the United States cost much less. Also, for national security reasons, a U.S. manufactured welding gas is preferred.

4. Alternatives Analyzed:

Since the TIME gas is proprietary, it is considerably more expensive than similar gas mixtures manufactured in U.S. Therefore, cost reductions may be achieved if another gas mixture comparable in composition demonstrates as good ballistic and weld performance as the TIME gas.

In February 1986 the U.S. Army and GDLS personnel decided reluctantly (by the Army) to approve the use of TIME gas with the understanding that a research project be carried out to find a lower cost and reliable (compositional variations are not well controlled and the gas comes from Canada) gas than the TIME gas. At the time of the approval, GDLS was already set up to use the TIME gas. GDL personnel in attendance agreed that this was the best course of action but declined to do the research themselves.

The research project to find a lower cost alternative to TIME welding gas was initiated by Dr. Steven Gedeon at U.S. Army Materials Technology Laboratory, Watertown, MA with VE funding support ($105,000) from TACOM (Encl 1). This project was initiated in October 1986 and preliminary results, released in September 1987, showed that a number of lower cost gases exist which are as good or better than TIME gas. GDLS has performed mechanical and ballistic tests on a number of these gases and has taken steps to use a two gas mix of 95% AR/5% O_2, known as M5, throughout their entire LATP facility.

This will amount to an estimated cost savings of approximately $1 million per year.

5. Recommendation:

It is recommended that the new lower cost two gas mix 95% AR/5% O_2 alternative to the TIME gas be approved for use in M1A1 tank fabrication at LATP to realize significant cost savings.

6. Impact:

   a. Improve productivity.

   b. Eliminate duplication.

   c. Achieve lower cost.

7. Implementation:

GDLS Inter-office Memo: R. Kratzenberg to C. Brown, 25 Mar 87, subject: HCD (WP-008) Proficiency Testing; GDLS Inter-office Memo: R. Kratzenberg to all LATP welders, 3 Sep 87, subject: Shielding Gas Change-over (Encl 2 and 3).

8. Summarize Offset Costs:

	Manhours	Cost
a. Conduct VE (prepare, process, develop support data) one manhour = \$25.00	100	\$2,500
b. Project cost (research and development)		105,100
TOTAL OFFSET COST		\$107,600

9. Summarize Estimated Cost Savings:

   a. Unit cost reduction

   \$98.83/cylinder TIME gas per Bob Kratzenberg, GDLS @ LATP (419-226-4267)

   -\$12.38/cylinder 95% AR/5% O_2 or M5 per Bob Kratzenberg, GDLS @ LATP

   \$86.45/cylinder

   b. Savings to be reported to TACOM

(1) First year (current) net savings: October 1987 - October 1988. 12000 cylinders of TIME gas were utilized annually, prior to conversion, to build 820 M1A1 or 14.64 cylinders/tank per Bob Kratzenberg, GDLS @ LATP (419) 226-4267.

After conversion 794 M1A1 will be built in the 12-month period beginning Oct 1987 (Encl 4).

794 tanks X 14.64 cylinder/tank = 11624 cylinders of M5 (95%AR/5% O_2) will be used.

The purchase of M5 welding gas will be in bulk quantity of equivalent amount to achieve additional cost savings.

(No. of units) X (unit cost reduction) - (offset costs).
(11624) X (\$86.45) - (\$107,600) = \$897,294 net savings.

(2) 2nd year (budget) net savings: Oct 1988 - Oct 1989.

720 M1A1 will be built in the 12-month period beginning Oct 1988 (Encl 4).
720 Tank X 14.64 cylinders/tank = 10541 cylinders of M5 will be used.

(No. of units) X (unit cost reduction) - (offset costs).
(10541) X ($86.45) - (0) = $911,269 net savings.

(3) 3rd year (Future Budget) net savings: Oct 1989 - Oct 1990.

718 M1A1 will be built in the 12-month period beginning Oct 1989 (Encl 4).
718 Tanks X 14.64 cylinders/tank = 10,512 cylinders of M5 will be used.

(No. of units) X (unit cost reduction) - (offset costs).
(10,512) X ($86.45) - (0) = $908,762 net savings.

10. Funding/Budget Data:

a. Budget activity (AMS codes) that offset costs are charged to: PAA.

b. Appropriation and budget activity that benefits from the VE savings: PAA.

11. Study documents enclosed.

12. Individuals that conducted the VESTU are:

Don Kendall, AMCPM-ABMS-SA
Dr. Steven Gedeon SLCMT-MCD-E

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Frank Wong, AMSTA-TMV

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Concurrence: Terrance M. Dean 12/3/87
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U.S. Army Materials Technology Laboratory
Watertown, Massachusetts 02172-0001
REDUCTION OF M1 WELD FABRICATION COSTS-
THE EFFECT OF WELD SHIELDING GAS COMPOSITION-
Steven A. Gedeon and James E. Catalano

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Key Words

Technical Report MTL TR 88-49, December 1988, 30 pp-
illus-tables, D/A Project 1L162105.AH84, AMCMS
Code 612105.H84

Armor steel
Welding
Fabrication

This project was initiated in October, 1986, to find a lower cost alternative to the weld shielding gas used for M1 fabrication at the U.S. Army Lima Tank Plant. The shielding gas in use was a newly patented mixture termed "Transferred Ionized Molten Energy" (TIME) gas. This gas was manufactured in Canada (and for a short time in Chicago, and now Columbus), and is much more expensive than other gas mixtures. The objective of this project is to evaluate a wide variety of weld shielding gas mixtures for welding the armor steel used in the U.S. Army M1 Abram's main battle tank. It is greatly desired to find an inexpensive gas mixture to replace the TIME gas used in 1986 at the Lima Army Tank Plant without decreasing weld performance. The gas mixtures were evaluated on gas cost, deposition rate, amount of weld hydrogen, bead profile, and amount of spatter. The effects of gas composition, weld voltage, electrode stickout, base metal composition, and nozzle geometry on welding characteristics were also evaluated. The results of this project show that a number of lower cost gases exist which are as good or better than the TIME gas. General Dynamics (GD) has performed mechanical and ballistic tests using Ar/5% O_2, TIME (Ar/He/CO_2/O_2), and STARGON (Ar/CO_2/O_2), and has taken steps to use 95% Ar/5% O_2 throughout their entire facility. This will amount to an estimated cost savings of approximately $1 million per year, which is documented in this report. Even further reductions are now being proposed with an MTL/GD joint value engineering proposal to TACOM.

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